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TREATMENT OF REACTIVE WASTES AT HAZARDOUS WASTE LANDFILLS

by

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16. ABSTRACT

This report is intended to provide an information base for personnel accepting hazardous waste at existing disposal sites, or performing remedial action at uncontrolled waste sites, to make the appropriate decisions regarding the disposition of reactive wastes. It emphasizes simple treatment and disposal schemes which are likely to be the most cost effective. It provides information on the hazards to be anticipated and the appropriate safety precautions necessary to protect personnel and property and to prevent any further environmental damage. The data in this report was obtained by reviewing the extensive in-house background information on the characteristics of reactive hazardous wastes; by reviewing the recent literature, particularly information pertaining to the handling and treatment of hazardous chemicals and finally by seeking information and comment from operators of hazardous waste disposal sites, including those specializing in the handling of reactive wastes.

The report is divided into three major sections: (1) Identification of Problem Wastes; (2) Identification of Treatment Alternatives; and (3) Identification of Data Gaps. Additional information on classes of chemical reactive wastes and treatment and disposal method identified from the literature, which were used to develop the more generalized schemes, is provided in Appendices A and B, respectively.

Conclusions and Recommendations are summarized separately.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the nation's environment and its effect on the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

This document is a preliminary study to provide information for personnel who handle reactive hazardous wastes. It examines the classification and special hazards encountered and describes alternate treatment and disposal technologies.

ABSTRACT

A preliminary study was undertaken to provide information for personnel who must make decisions about the disposition of reactive hazardous wastes (Federal and State personnel, employees accepting hazardous wastes at existing disposal sites, and coordinators performing remedial action at uncontrolled waste sites). These wastes generally display one or more acute physical or chemical hazards and form an immediate threat to human health or the environment. Though Federal regulations place reactive wastes in a special category, they do not identify specific treatment methods.

In response to the need for better information, this report describes problem wastes, examines treatment alternatives, and identifies data gaps. Emphasis is placed on simple treatment and disposal schemes that are likely to be the most cost effective. The measures described are either already in use or they are promising techniques that require little further development and have a high probability of success. Information is provided on the possible hazards and the appropriate safety precautions to protect personnel and property.

This report was submitted in fulfillment of Contract No. 68-01-5949 by Arthur D. Little, Inc., under the sponsorship of the U.S. Environmental Protection Agency. The report covers the period October 1982 to December 1982, and work was completed as of December 31, 1982.

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CECOS International
Chemical Waste Management, Inc.
SCA Services, Inc.
Battery Disposal Technology, Inc.
Advanced Environmental Technology Corporation (AETC)
Emergency Technical Services Corporation (ETSC)

Their contributions are gratefully acknowledged.

SECTION 1

INTRODUCTION

Though reactive hazardous wastes constitute only about 5% of all hazardous wastes, extreme caution must be used during their transportation, handling, storage, treatment, and disposal. These wastes generally display one or more acute physical or chemical hazards and form an immediate threat to human health or the environment. For example, many wastes can cause fires or explosions if improperly handled. The Resource Conservation and Recovery Act provides a special classification for reactive wastes and prohibits certain treatment and disposal methods for them, but the regulations do not specify treatment methods that are applicable. Thus, adequate information on handling reactive wastes is very much needed, but it is difficult to provide because of the wide variety of chemical behavior that can be expected from materials in this category.

This report is intended to provide an information base for personnel who must make decisions about the disposition of reactive wastes--Federal and state personnel, employees accepting hazardous wastes at existing disposal sites, or coordinators performing remedial action at uncontrolled waste sites. However, the information in this report is provided as a guide and not as a substitute for the detailed information to be obtained from the standard reference works cited in the bibliography (p. 24). Emphasis is placed on simple treatment and disposal schemes that are likely to be the most cost effective, environmentally acceptable, and do not pose an unusual safety hazard. The measures described are either already in use or they are promising techniques that require little further development and have a high probability of success. Information is provided on the hazards to be anticipated and the safety precautions needed to protect personnel and property and to prevent any further environmental damage.

The report is divided into three major sections: (1) identification of problem wastes, (2) identification of treatment alternatives, and (3) identification of data gaps. Appendix A lists a representative sample of chemical compounds or species that can be classified as reactive hazardous wastes (the total number that could be listed is very large). Though many of these materials are not routinely sent for treatment and disposal, most appear as wastes periodically, and even small quantities (1 kg) may pose a distinct and severe hazard to health. Appendix B lists alternative treatment technologies identified from the literature.

The data in this report were obtained through three sources: A review of extensive in-house background information on the characteristics of reactive hazardous wastes, a review of the recent literature (particularly information on the handling and treatment of hazardous chemicals), and direct comment and information from operators of hazardous waste disposal sites (including those specializing in the handling of reactive wastes). The three steps are described as follows:

1. The in-house background on existing hazardous wastes was reviewed to identify examples of reactive hazardous wastes, to determine their characteristics, and to document information about treatment and disposal practices.

2. A comprehensive literature search was undertaken, to provide examples of specific classes of reactive wastes and information on potential hazards and safety precautions. Particular emphasis was placed on a number of widely available standard works on hazardous chemicals. The major sources are listed in the bibliography.

   The computerized literature was searched by means of the NIH/EPA Chemical Information System (CIS), Oil and Hazardous Materials Technical Assistance Data System (OHM-TADS). Material pertaining to definition of the reactivity codes was obtained from the Federal Register of Regulations (FR 45, p33122, May 19, 1980). Definitions for the various classes of explosives was obtained from the Code of Federal Regulations (CFR 49.173, 1981).

3. A selected group of field interviews was undertaken to provide additional information on actual experience and field practices. Personnel from the following six companies provided information that is incorporated into this report.

   CECOS International
   Chemical Waste Management, Inc.
   SCA Services, Inc.
   Battery Disposal Technology, Inc.
   Advanced Environmental Technology Corporation (AETC)
   Emergency Technical Services Corporation (ETSC)

   CECOS, Chemical Waste Management, and SCA Services are full- service companies who handle certain types of reactive hazardous wastes. They do not normally handle explosive materials. Battery Disposal Technology specializes in water-reactive wastes but does not treat explosive materials. AETC and its associated company, ETSC, handle a wide variety of reactive wastes and specialize in the treatment and disposal of explosive wastes.

SECTION 2

CONCLUSIONS

1. Reactive wastes exhibit a broad spectrum of chemical behavior, and therefore a classification scheme is needed that allows for this diversity. Reactive wastes can be broadly classified into two groups: those that may explode[1] and those that do not. Many of the wastes that do not explode are water reactive. Some are also reactive to air (e.g., pyrophoric), and some only react in acid solutions (e.g., cyanides and sulfides). Overall, the eight reactivity classes listed in the Federal Register[2] account for the chemical diversity of reactive wastes quite well, but a further subdivision of Classes I and II is proposed to allow for a better definition of wastes that are pyrophoric, polymerizable, or oxidizers.

2. Reactive wastes represent acute hazards to personnel and property in addition to potential longer-term environmental hazards. Blast protection, protective fire resistant clothing, and breathing apparatus may have to be used as appropriate to handle reactive wastes. Materials that may cause explosions (particularly wastes that are not well characterized) should not be moved but should be isolated from other wastes, property and personnel. Wastes that are not subject to explosion should be moved to a safer location to isolate them from other wastes, property, and personnel. Further containment, handling, and treatment requirements can then be determined.

3. No universally applicable technique exists for isolating and containing all reactive wastes. Hazards in transporting, handling, and storing water-reactive wastes can be reduced by diluting the material with an inert solid or absorbent (vermiculite, sand, etc.) and protecting them from moisture. Conversely, explosive materials are best kept in a wet state. Most explosives are much more shock- and friction-sensitive when dry. Department of Transportation (DOT) regulations forbid the transport of certain recognized explosives unless they are diluted with water or a solvent such as alcohol. For many types of explosive wastes, any

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[1] See page 7 for definition of the term explosive.
[2] Federal Register, Vol. 45, No. 98, p. 33122, May 19, 1980.

handling or transportation can be extremely hazardous, particularly since containers may be deteriorated and the condition of the waste may not be known. Wastes of this type must often be destroyed onsite to avoid handling and transportation.

4. Two destruction techniques appear to be more broadly applicable than the others. The first is open burning, which may apply to most or all reactive materials except cyanides and oxidizers. This method has been applied to various types of water-reactive materials (e.g., alkali metals) and avoids some of the complex equipment required for other destruction techniques. Open burning has also been applied to the destruction of explosives and is still a permitted use for destruction of explosive wastes that cannot be safely incinerated. Local permit requirements for open burning may prevent the use of this method at some sites, except as an emergency response technique.

   Destruction of reactive wastes by reaction with water (Classes I through IV) is the second broadly applicable technique. Equipment requirements may be more complex than for open burning, but energy requirements are low.

   Destruction of water-reactive wastes in aqueous media may lead to the production of explosive or toxic gases that must be vented or scrubbed from the atmosphere. Application of open burning to these wastes results in different reactions that generally avoid the formation of explosive or toxic gases. Explosive wastes are stable in water, but some can be destroyed by alkaline solution.

5. Reaction with calcium hypochlorite (or other similar chlorine-containing compounds) is a well developed and widely practiced technique for the destruction of inorganic cyanides. Though other techniques are available, little advantage appears to exist in supplanting this technique with any other. Sulfides can be oxidized by the same technique. Organic sulfides and cyanides can be destroyed by combustion.

6. The field interviews covered three major companies in hazardous waste management and three companies specializing in management of reactive wastes. Each company has its own procedures for managing reactive wastes and is selective about the type of wastes it will accept. The major companies tend to be conservative and refer the more dangerous reactive wastes (e.g., explosive wastes) to the specialist companies.

   All the companies stressed the importance of obtaining expert advice about the specific waste and its location before attempting to handle it. Some wastes (e.g., ethers) are easily handled as solvents when they are new but may become extremely dangerous after aging because of peroxide formation.

7. A number of data gaps have been identified by this preliminary study. Some of the most important are:

(a) Lack of a comprehensive listing of hazardous wastes detailing reactive properties, hazards, and necessary safety precautions (though a useful body of data does exist in the OHM-TADS computerized hazardous materials data base[1]).

(b) Lack of inventory data indicating the types and quantities of reactive wastes being received by Treatment, Storage and Disposal Facility (TSDF) operators.

(c) Limited documentation of the effectiveness of simple, broadly applicable techniques for isolation or destruction of reactive wastes.

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[1]NIH/EPA Chemical Information System (CIS), Oil and Hazardous Materials, Technical Assistance Data System (OHM-TADS).

SECTION 3

RECOMMENDATIONS

1. Further work should be done to expand the documentation of reactive hazardous wastes contain in the appendices to this report and make it comprehensive. Much of this information is available in the literature or from industry. The data should be accessed by an expanded field interview program and then should be documented in a way which makes them more accessible to TSDF operators. For those wastes where actual data is not available, conservative estimates should be made based on expected chemical properties.

2. Simple techniques and equipment should be developed for destroying reactive wastes by reaction in water or aqueous media. Information is needed on appropriate feed rates, venting or scrubbing of off-gases, and treatment and disposal of spent reaction and scrubber solutions.

3. A program should be instituted to develop further the techniques and equipment for the open burning of reactive wastes. The program should define the following parameters: maximum quantities of wastes to be treated, potential hazards, necessary safety precautions for personnel and equipment, requirements for auxiliary fuel, and disposal of residuals.

4. Estimates should be developed to compare the costs of destroying reactive wastes with the costs of existing technologies, particularly long-term containment or landfill.

SECTION 4

IDENTIFICATION OF PROBLEM WASTES

CLASSIFICATION SCHEME FOR REACTIVE WASTES

The initial classification scheme adopted in this work was that published as part of the RCRA Federal regulations. This classification scheme (Table 1) separates reactive wastes into eight different classes. In practice, reactive wastes exhibit a wide range of chemical behavior, and many chemicals do not fall exclusively into one of these classes. But, two broad subdivisions can be established between those reactive wastes that may explode (Classes III, VI, VII, VIII) and those wastes that do not.

The term "explosive" as it is used in the Federal Register (and in general usage) covers a wide range of physical and chemical effects which are accompanied by a rapid and violent release of energy. For example, explosion may be caused by any of the following which are listed in order of increasing severity.

1. Generation of a large volume of gas that causes its container to burst due to excess pressure.

2. Rapid decomposition or combustion, with the evolation of gas and/or heat.

3. Detonation with formation of violent shock wave similar to that formed by a high explosive.

Explosion requires the presence of an initiating agent such as heat, shock, ignition, etc. The severity of an explosion may vary with its surroundings and the ambient conditions. Individual chemicals (and waste) therefore can exhibit a range of explosive behavior. With current procedures explosion can be prevented or controlled.

Subdivisions under some reactivity classes have been defined in this report to adequately describe the type of reactive behavior. For example, Class I is subdivided into three sections: (Ia) pyrophoric materials, (Ib) polymerizable materials, and (Ic) oxidizers. The reactive effects, consequent hazards and necessary safety precautions are somewhat different in each case. Similarly, Class II is provided with two subdivisions: (IIa) those materials which cause a large evolution of heat in contact with water but do not decompose, and (IIb) those materials that decompose in water and usually decompose (more slowly) in moist air. A format for describing each of the different

TABLE 1

REACTIVE WASTE CLASSES AS DEFINED BY THEIR
REACTIVITY CHARACTERISTIC IN THE FEDERAL REGISTER

Class	Reactivity Characteristic
I	It is normally unstable and readily undergoes violent change without detonating.
II	It reacts violently with water.
III	It forms potentially explosive mixtures with water.
IV	When mixed with water, it generates toxic gases, vapors or fumes in quantity sufficient to present a danger to human health or the environment.
V	It is a cyanide- or sulfide-bearing waste, when exposed to pH conditions between 2 and 12.5, can generate toxic gases, vapors or fumes in a quantity sufficient to present a danger to human health or the environment.
VI	It is capable of detonation or explosive reaction if subjected to a strong initiating source or if heated under confinement.
VII	It is readily capable of detonation or explosive decomposition or reaction at standard temperature and pressure.
VIII	It is a forbidden explosive as defined in 49 CFR 173.51, or a Class A explosive as defined in 49 CFR 173.53 or a Class B explosive as defined in 49 CFR 173.88.

Source: Federal Register, Vol. 45, No. 98, P. 33122, May 19, 1980.

reactivity classes is given in the text that follows. Each subsection provides a definition of the class, the properties of reactive wastes in that class, specific examples (representative only), the hazards associated with that type of reactive material, and the necessary safety precautions.

SAFETY PRECAUTIONS

Reactive wastes can cause acute adverse effects to human health and must therefore be stored, handled, treated, and destroyed by experienced operators. Three types of acute effects can be distinguished: explosion, fire, and production of toxic gases. For many wastes, at least two of these reactions may occur simultaneously. Materials that may detonate must be treated with extreme caution. Transportation of hazardous materials is extensively covered by DOT regulations.[1] Many reactive wastes can be classified under these regulations. In some cases, the requirements may be more stringent than necessary for transportation of wastes. But, some wastes may be dangerous and unacceptable for transportation because of aging, lack of inhibitors, or deterioration of the container. In those cases, it becomes necessary to seek expert assistance and treat or dispose of the material on site as safely as possible.

Reactivity of individual chemicals in a specific chemical class, (e.g., alkali metals) varies considerably. This rate of activity may also vary as a result of aging or contamination by other wastes. Thus, it is prudent to handle, treat, and dispose of such materials in accordance with the harmful effects of the most hazardous member of that particular class.

The proceeding subsections indicate the nature of safety precautions (personnel, equipment, and property protection) that should be taken for each class of reactive wastes. This information is only intended to provide a general guide and is not sufficiently detailed to permit handling of reactive wastes without prior experience and more detailed information about the specific waste. In addition, other requirements may be imposed by local codes and ordinances.

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[1] Transportation, Hazardous Material Regulations Code of Federal Regulations (CFR) 49 parts 171-175, p. 51 et seq., 1981.

Class I

Definition

It is normally unstable and readily undergoes violent change without detonating.

Properties

IA: Pyrophoric. Spontaneous ignition in contact with air.

IB: Polymerizable. Spontaneous polymerization in contact with air or on heating.

IC: Oxidizers. Violent reaction in contact with organic materials or strong reducing agents.

Specific Examples

IA: Metal alkyls, finely divided metal powders (Magnesium, Aluminum, and Zinc).

IB: Divinyl benzene.

IC: Perchloric acid, fuming nitric acid.

Hazards

Acute physical harm from fire or mechanical explosion caused by rupturing of containers.

Safety Precautions

Full protective, fire resistant clothing with gloves and face shield.

Seek expert advice before handling.

Take precautions to avoid rupture of the container. If the container is intact, move the material and isolate (from other incompatible wastes) personnel, and equipment.

Pyrophoric wastes - prevent contact with air or water.

Polymerizable wastes - keep cool (beloW 70°C), prevent contact with water.

Oxidizers - prevent contact with organic materials (paper, wood, cellulose, solvents, oil, etc.).

Class II

Definition

It reacts violently with water.

Properties

IIA: Causes a large evolution of heat in contact with water.

IIB: Decomposes in moist air and violently decomposes with liquid water.

Specific Examples

IIA: Sulfuric acid, chlorosulfonic acid

IIB: Phosphorus pentachloride, titanium tetrachloride

Hazards

Physical harm from fuming in moist air causing exposure to corrosive and/or toxic gases. Splashing of material due to the violent reaction and subsequent skin contact with corrosive materials.

Safety Precautions

Protective acid resistant rubber or plastic clothing with gloves and face shield.

Seek expert advice before handling.

Take precautions to avoid rupture of the container. If corroded, cover to prevent access of moisture. If the container is intact or sealed, move the material and isolate from other incompatible wastes and prevent exposure to water or moist air.

Class III

Definition

It forms potentially explosive mixtures with water.

Properties

Decomposes violently in water with evolution of heat and flammable gases which may ignite if exposed to a source of ignition. Evolution of heat with water may be sufficient to cause auto-ignition (and explosion).

Specific Examples

Alkaline metals, alkaline metal hydrides, alkaline metal nitrides.

Hazards

Acute physical harm from fire or explosion caused by ignition of flammable gases.

Safety Precautions

Full protective fire resistant clothing with gloves and face shield.

Seek expert advice before handling.

Take precautions to avoid rupture of the container. Cover to prevent access of moisture. If the container is intact, move the material and isolate from other incompatible wastes. Exclude all possible sources of ignition - sparks, heat flames.

Provide ventilation to disperse flammable gases. Use of water as a fire extinguisher may aggravate the fire potential hazard. Use dry sand to smother material.

Class IV

Definition

When mixed with water, it generates toxic gases, vapors, or fumes in a quantity sufficient to present a danger to human health or the environment.

Properties

Reacts rapidly with water with the production of gases or vapors which are acutely toxic to human health.

Specific Examples

Alkaline metal phosphides, toluene diisocyanate

Hazards

Acute adverse health effects through inhalation or possibly through skin contact with hazardous toxic vapors.

Safety Precautions

Wear self-contained breathing apparatus. Full protective clothing with gloves and face shield.

Seek expert advice before handling.

Take precautions to prevent rupture of the container. IF the container is intact, move the material and isolate from other incompatible wastes and personnel. Seal with adhesive tape or place inside polyethylene bag to prevent contact with moisture and provide adequate ventilation to disperse toxic gases.

Class V

Defintion

It is a cyanide or sulfide-bearing waste, which when exposed to pH conditions to between 2 and 12.5 can generate toxic gases, vapors, or fumes in a quantity sufficient to present a danger to human health or the environment.

Properties

Cyanides and sulfides produce extremely toxic hydrogen cyanide gas or hydrogen sulfide gas, respectively, on contact with acids or materials which form acids in the presence of moisture or liquid water.

Specific Examples

Potassium cyanide, other metal cyanides, lead sulfide, and similar metal sulfides. Organic cyanides and sulfides.

Hazards

Acute toxic effects from inhalation of hydrogen cyanide or hydrogen sulfide. Acute toxic effects from skin contact with hydrogen cyanide.

Safety Precautions

Wear self-contained breathing apparatus. Full protective clothing with gloves and face shield.

Seek expert advice before handling.

Take precautions to prevent rupture of the container. If the container is intact, move the material and isolate from other incompatible wastes and personnel. Seal to prevent contact with moisture and provide adequate ventilation to disperse toxic gases.

Class VI

Definition

It is capable of detonation or explosive reaction if it is subjected to a strong initiating source or if heated under confinement.

Properties

Detonation or explosion if heated above ambient temperature (20°C) or if exposed to an initating source such as shock, mechanical shock, spark or flame, or a catalyst which accelerates decomposition.

Examples

Lead amide, parathion, isoamyl nitrite, ammonium nitrate, hydrozene.

Hazards

Capable of causing acute physical damage to human health and property through energy transfer resulting in a violent mechanical force accompanied by shock, heat and possibly fire.

Safety Precautions

It is imperative to seek expert advice before approaching containers of these materials. Do not touch or move. Do not subject to heat or shock.

Wear full protective fire-resistant clothing before approaching the container location.

Proceed with extreme caution. If possible, isolate by moving all other hazardous materials in the immediate vicinity. Shield the container from sun to prevent heating. Clear the area of other valuable equipment and property.

It is often advisable to provide destruction of Class VI material on-site to avoid additional hazards during transportation.

Class VII

Definition

It is readily capable of detonation or explosive decomposition or reaction at standard temperature and pressure.

Properties

Capable of detonation or explosive decomposition under ambient conditions of temperature and pressure without any external initiating source.

Specific Examples

Organic peroxides such as benzoyl peroxide, acetyl peroxide, other materials which may form peroxides on standing, e.g., ethers, dioxane and tetrahydrofuran.

Hazards

Capable of causing acute physical damage to human health and property through energy transfer resulting in a violent mechanical force accompanied by shock, heat and possibly fire.

Safety Precautions

It is imperative to seek expert advice before approaching containers of these materials. Do not touch or move. Do not subject to heat or shock.

Wear full protective fire-resistant clothing before approaching the container location.

Proceed with extreme caution. If possible, isolate by moving all other hazardous materials in the immediate vicinity. Shield the container from sun to prevent heating. Clear the area of other valuable equipment and property.

It is often advisable to provide destruction of Class VI material on-site to avoid additional hazards during transportation.

Class VIII

Definition

It is a forbidden explosive as defined in 49CFR173.51, or a Class A explosive as defined in 49CFR173.53, or a Class B explosive as defined in 49CFR173.88.

Properties

Forbidden Explosives. Capable of detonation or explosive decomposition under ambient conditions, considered too dangerous for transportation.

Class A Explosives. Highly explosive, capable of detonation but safe to transport if handled in accordance with DOT regulations and segregated from initiating compounds.

Class B Explosives. Flammable explosives capable of rapid combustion but not detonation. Safe to transport in accordance with DOT regulations.

Specific Examples

Forbidden Explosives. Diethylene glycol dinitrate, acid metal salt or ammonium salt and chlorate.

Class A Explosives. Commercial dynamite, desensitized nitroglycerine, initiating explosives such as lead azide, mercury fulminate.

Class B Explosives. Rocket propellants, smokeless powder.

Hazards

Capable of causing acute physical hazard to human health and property through energy transfer resulting in a violent mechanical force accompanied by shock, heat, and possibly fire.

Safety Precautions

It is imperative to seek expert advice before approaching containers of these materials. Do not touch or move. Do not subject to heat or shock.

Wear full protective fire-resistant clothing before approaching the container location.

Proceed with extreme caution. If possible, isolate by moving all other hazardous materials in the immediate vicinity. Shield the container from sun to prevent heating. Clear the area of other valuable equipment and property.

It is often advisable to provide destruction of Class VIII material on-site to avoid additional hazards during transportation.

SECTION 5

IDENTIFICATION OF TREATMENT ALTERNATIVES

DEFINITION OF ALTERNATIVES

The first approach to defining alternative treatment technology was to assess the background information and search the literature for specific examples using commonly recognized chemicals or waste materials from each reactivity class. An example of the format used for this analysis is shown in Table 2. The data organized under this format are collected together in Appendix B. At first, the treatment technology was separated into three groups: (1) isolation or containment, (2) hazard reduction, and (3) detoxification. In many instances, it was found that the difference between groups 2 and 3 were attributable more to differences in the chemical properties of the waste than to differences in treatment technology. Thus, these two subcategories were combined into a single sub-category entitled "Destruction." Each technology was assessed qualitatively in terms of the follcwing criteria: Technical feasibility; applicability; chemicals and equipment requirements; operator requirements; residual production; advantages/disadvantages; and relative cost.

Differences in ranking were expressed in the following way:

+ - Above Average Ranking
0 - Average Ranking
- - Below Average Ranking
NA - Not Applicable

For example, in terms of feasibility, a plus (+) ranking would indicate that this is a well-established, well-documented technology that has been used commercially on similar wastes. A negative (-) ranking would indicate that the technology appears feasible as demonstrated by laboratory experiments, but actual commercial operation or applicability to real wastes has not been well documented. Further explanation to backup the qualitative ranking for each of the technologies described is also provided in Appendix B.

The cost ranking was the most subjective element in this list because of the general absence of cost data for the types of technology described and evaluated in this report. A plus (+) value indicates that the cost is expected to be lower than average because the technique requires less than average operator experience and only simple low-cost equipment. A negative (-) value indicates an expected higher than average cost because the technique requires more complex chemical processing equipment, instrumentation or

TABLE 2. FORMAT FOR EVALUATION OF TREATMENT TECHNOLOGY

Waste	Treatment Group	Technology	Treatment Feasibility	Applicability	Chemical & Equipment	Operator Requirements	Residual Production	Advantages/Disadvantages	Relative Cost	

analysis, and a high level of operator experience due to the difficulty of operating the process or the hazards involved.

The purpose of isolation containment technology is to reduce the immediate hazards associated with the reactive wastes so that it can be handled, stored, and transported in accordance with accepted practices, e.g., DOT regulations for the chemicals involved.

ISOLATION/CONTAINMENT

From an evaluation of the available data, we have selected eight isolation/containment techniques which are broadly applicable to a number of reactive waste classes. Applicability is indicated in Table 2 by a for applicable, x for not applicable and ? where the technique may only be acceptable for some members of the reactive class. Not surprisingly no technique is applicable to all 8 classes of reactive wastes. The primary dividing line is between those classes which can cause explosion or detonation (VI, VII, VIII) and those which do not. The general procedure for each technique is indicated in Table 3. Detailed specific operating procedures for each of these methods have not been documented or evaluated for all the examples indicated. The selection has been made on the basis of background knowledge, experience, and the available literature data. In addition, the appropriate safety procedures must be followed.

Two procedures stand out as being generally applicable. The first involved dilution, by mixing with excess solid and sealing in a dry container. The solid can be an inert material such as sand or vermiculite or an absorbent such as ground clay (kitty litter) or limestone. Some wastes such as acids or acid-forming materials (e.g., $TiCl_4$) may react with limestone evolving gas which can pressurize and cause failure of a hermetically sealed container. This method is generally applicable for reactive waste classes I - V.

The second procedure involves mixing with water and excess inert or absorbent solid. Wet explosive materials are less susceptible to shock and heat. Transportation of many explosive materials in the dry state is forbidden by DOT regulations. Use of ethanol/water mixtures may have an advantage in solubilizing some organic wastes. Alkaline solutions may have an advantage in stabilizing or decomposing some wastes.

HAZARD DESTRUCTION

A listing of broadly applicable techniques for hazard destruction is shown in Table 4. As might be anticipated, the nine techniques listed are not as broadly applicable to a group of waste classes as for containment isolation because destruction requires more specific technology. The same symbols are used in this table (a, x and ?) with the addition of an 0 in Class V. The latter indicates that mixing with weak alkali may stabilize reactive cyanides and sulfides, but will not cause destruction.

Mixing with an inert solid, such as vermiculite, followed by open burning may be the most broadly applicable technique (it is not applicable to Class V, Cyanides and Sulfides).

TABLE 3. ISOLATION/CONTAINMENT TECHNIQUES

	APPLICABILITY TO REACTIVE WASTE CLASS										
	I			II		III	IV	V	VI	VII	VIII
Procedure	a	b	c	a	b						
Mix with excess inert solid material and seal in a dry container	x	x	a	a	a	a	x	x	x	x	x
Mix with excess solid absorbent and seal in a dry container	a	a	a	a	a	a	a	a	x	x	x
Mix with excess solid absorbent in a vented container	x	x	a	a	x	a	x	x	x	x	x
Mix with water and excess inert solid material	x	x	a	x	x	x	x	x	a	a	a
Immerse in alcohol/water mixture	x	x	x	x	x	x	x	x	a	a	a
Immerse in alkaline solution	x	x	x	x	x	x	x	a	x	x	x
Immerse in kerosene	x	x	x	x	x	a	?	x	x	x	x
Encapsulate in a cement matrix	x	x	a	x	x	x	x	?	a	a	a
Mix with excess water	x	x	a	a	a	a	x	x	x	x	x

Code: a = applicable, x = not applicable, ? - may be applicable to some members of the class.

TABLE 4. DESTRUCTION TECHNIQUES

Procedure	APPLICABILITY TO REACTIVE WASTE CLASS										
	I			II		III	IV	V	VI	VII	VIII
	a	b	c	a	b						
Mix with excess water and vent gases	a	?	a	a	a	a	x	x	x	x	x
Mix with weak alkali	a	x	a	a	a	?	a	0	x	x	x
React with calcium hypochlorite	x	x	x	x	x	x	a	a	x	x	x
React with ferrous chloride solution (reducing agent)	x	x	a	x	?	?	x	x	?	?	x
Mix with alcohol/water and burn	a	x	x	x	x	x	x	x	a	a	a
Mix with solid (vermiculite) and burn	a	a	x	x	a	a	a	x	?	?	?

Code: a = applicable, x = not applicable, ? - may be applicable to some members of the class.

Water reactive compounds should be kept dry and may need auxiliary fuel to ensure complete destruction. Incineration of some water reactive wastes, e.g., alkali metal wastes, is used commercially.[1] One environmental problem with open burning of reactive wastes is potential air pollution from release of toxic gases, e.g., sulfur dioxide, nitrogen oxides, and hydrogen chloride. Thus, to be environmentally acceptable only small amounts can be destroyed in this manner. Open burning of explosive wastes is used to destroy both commercial and military explosive wastes[1]. Open pit burners have been developed and used by DuPont, Union Carbide, and others. Visible smoke can be eliminated but this type of incineration does not provide good control over particulate or noxious gas emissions. This type of burning has proven effective for the destruction of many types of explosives and is particularly effective with solid wastes. Explosive materials are destroyed while wet which increases the auxiliary fuel requirements.

Hydrolysis by controlled reaction with excess water is an effective technique for many reactive wastes in Classes I - IV. Process efficiencies may be increased by use of alkaline solutions which may also serve as scrubbing solutions for effluent toxic gases. This process is used commercially for the destruction of acidic, water reactive wastes. It is also applicable to reactive metals and their reactive compounds. Venting must be provided to prevent accumulation of flammable or toxic gases.

Alkaline chlorination is a widely used technology for destruction of cyanides and sulfides. The level of sophistication (equipment, control, analysis) increases with the scale of operations. However, the technique can be safely used in small-scale, batch operations using sodium or calcium hypochlorite as the oxidizing agent.

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[1] R.S. Ottinger, et al., Recommended Methods of Reduction Neutralization, Recovery or Disposal of Hazardous Waste, PB 224 582, NTIS, Springfield, VA, August 1973.

SECTION 6

DATA GAPS AND RESEARCH NEEDS

The data gaps and needs for research on the treatment and disposal of reactive hazardous wastes are listed as follows.

1. The OHM-TADS computerized data base is very useful for charting the properties, hazards, treatment requirements and safety precautions for reactive hazardous wastes. But, many fairly common examples of reactive hazardous wastes are not presently included in the OHM-TADS system. The relevant data on chemicals and other wastes now included in this system should be collected and evaluated to increase its utility to hazardous waste personnel. A listing of incompatible reactive wastes should be developed because mixing of certain incompatible wastes may cause an unacceptably large increase in hazard or even a change in the type of hazard to be expected, i.e., from fire to explosion. This is particularly important to personnel who are assembling lab packs of chemicals for transportation and disposal at remote sites.

2. EPA and others have developed directories of EPA registered, hazardous waste transporters and TSDF operators, together with information on the types of wastes that they process. However, reactive wastes often present acute hazards unlike other hazardous wastes and there is an urgent need for a separate directory or section which clearly indicates those companies who are qualified and willing to accept specific classes of reactive wastes together with a list of wastes they are able to accept for treatment or disposal.

3. Most reactive wastes occur in small quantities of 1 to 2 pounds, but 55-gallon drums or even tank-car loads are by no means uncommon. The TSDF operator needs guidance on the maximum quantity of a particular waste which can be handled by simple procedures.

4. Further research is required to develop an inventory of the specific type and quantities of reactive wastes which are presently entering the market for treatment and disposal. The inventory should differentiate between small quantities of lab chemicals and larger volumes of industrial wastes, and assist in defining future needs for waste disposal technology and services.

5. Two generalized simple techniques have been identified for the destruction of a variety of reactive hazardous wastes classes. The most widely applicable technique appears to be a modified form of open

burning, and the second is reaction with water for those wastes that are destroyed by this treatment. But, simple, effective equipment for this purpose has not been developed and tested by either the Federal government or commercial firms (although some may be in use within specific companies). Thus, there is an urgent need for further development of these two methods to determine the form of equipment which is most suitable, the maximum quantities of material that can be safely handled, reliable, safe operating procedures, and techniques for treating effluents. Finally, capital and operating cost estimates for such processes need to be developed.

6. Data on true costs for treatment and disposal of reactive wastes by simple techniques have not been developed. The components of the cost data also fall outside the typical engineering cost element approach and are highly weighted by elements such as transportation, handling, personnel protection, recontainerization, and analysis. There is a need to develop applicable cost data based on the existing field experience and generalized so as to be applicable to a wide spectrum of reactive wastes.

7. Evaluation of field experience was unavoidably restricted by the time and budget limitations of this study. This deficiency should be remedied by a more extensive field interview program to more fully document experience and present practices.

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APPENDIX A

REPRESENTATIVE CHEMICALS IN EACH REACTIVITY CLASS

Class I

Reactivity Characteristic - Normally unstable and undergoes violent change without detonating.

IA: Pyrophoric. Spontaneous ignition in contact with air.

IB: Polymerizable. Spontaneous polymerization in contact with air or on heating.

IC: Oxidizers. Violent reaction in contact with organic materials or strong reducing agents.

Examples	Nature of Hazard
IA PYROPHORIC	
Metal alkyls (Mg, Zn, Al, Ti, Sn)	ignites in air
Sodium hydrazide	ignites in air
Metal powders, finely divided (Mg, Al, Zn, Ni)	oxidizes in air becoming incandescent
Ferrous sulfide	oxidizes in air becoming incandescent
Sodium superoxide	decomposes liberating oxygen
Phosphorus	ignites in air
Manganese bicyclopentadienyl	ignites in air
Ammonium persulfate	ignites in air
IB POLYMERIZABLE	
Divinyl benzene	liberation of heat which may lead to ignition
IC OXIDIZERS	
Perchloric acid Chromic acid Nitric acid Hydrogen peroxide (above 90%)	rapid intense reaction with organic materials which may cause ignition and fire

Class II

Reactivity Characteristic - Reacts violently with water.

IIA. Causes a large evolution of heat in contact with water.

IIB. Decomposes in moist air and violently decomposes with liquid.

Examples	Nature of Hazard
IIA HEAT EVOLUTION	
Sulfuric acid Oleum Chlorosulfonic acid Phosphorus trioxide and pentoxide	vigorous reaction, liberation of heat splashing of corrosive liquid
IIB DECOMPOSITION	
Acetyl halides Phosphorus halides Titanium tetrachloride	vigorous reaction, liberation of heat and acid fumes
Glyoxal	polymerizes rapidly

Class III

Reactivity Characteristic - Forms potentially explosive mixtures with water.

Examples	Nature of Hazard
Alkali metals	reaction, evolves H_2
Alkaline earth metals	reaction, evolves H_2
Alkali metal silicides	reaction, evolves silane (SiH_4)
Aluminum hydride	violent reaction, evolves H_2
Lithium borohydride	violent reaction, evolves H_2
Alkali metal nitrides	reaction, evolves H_2 and NH_3
Alkali metal hydrides	reaction, evolves H_2
Alkali metal carbides	reaction, evolves acetylene

Class IV

Reactivity Characteristic - When mixed with water, generates toxic gases, vapors or fumes in a quantity sufficient to present a danger to health or the environment.

Examples	Nature of Hazard
Alkali metal phosphides	decomposition, evolves phosphine (PH_3)
Aluminum phosphide	decomposition, evolves phosphine (PH_3)
Phosphorus sulfides	decomposition, evolves H_2S
Phosphorus halides	decomposition, evolves HX
Toluene diisocyanate	violent decomposition, evolves toluenediamine

Class V

Reactivity Characteristic - A cyanide- or sulfur-bearing waste that, when exposed to pH conditions between 2 and 12.5, can generate toxic gases, vapors or fumes in a quantity sufficient to present a danger to human health or the environment.

Examples	Nature of Hazard
Metal cyanide salts of sodium, potassium, copper, silver, and gold Organic cyanide compounds	liberate HCN in the presence of acids
Metal sulfide salts Organic sulfides and mercaptans	liberate H_2S in the presence of acids

Class VI

Reactivity Characteristic - Capable of detonation or explosive reaction if subject to a strong initiating source or if heated under confinement.

Examples	Nature of Hazard
Lead amide	explodes in hot water
Sodium amide	explodes in hot water
Thallous nitride	explodes with shock, heat, or exposure to water
Metal azides	explode with shock or heat
Brominated organic compounds	explode with shock or heat
Benzene diazonium salts	explode with slight shock
Ammonium picrate	explodes with shock or heat
Ammonium tetrachromate	explodes with heat
Metal periodates	explodes with heat
Parathion	explodes with heat
Organic perchlorates	explodes with heat
Isoamyl nitrite	explodes with heat
Chloropicrin	explodes with heat
Ammonium nitrate	explodes with heat
Ammonium chlorate	explodes with heat

Class VII

Reactivity Characteristic - Readily capable of detonation or explosive decomposition at STP.

Examples	Nature of Hazard
Ammonium chlorate	unstable, explosive decomposition
Anisoyl chloride	unstable, explosive decomposition
Organic azides	unstable, explosive decomposition
Ammonium chlorate	unstable, explosive decomposition
Metal azides	ignite in air, may explode
Acetyl nitrate	unstable, explodes with shock
Acetyl peroxide	unstable, explodes with shock
Benzoyl peroxide	unstable, explodes with shock
Sodium benzyl	ignites in air
Chloroacetone	polymerization, explodes with shock
Ethers	flammable, form explosive peroxides on aging
Hydrazine and derivatives	ignites in air even when adsorbed out porous materials, may explode
Peroxy acids	explosive, shock sensitive
Dioxane	flammable, forms explosive peroxides on aging
Tetrahydrofuran	flammable, forms explosive peroxides on aging

Class VIII

Reactivity Characteristic - A forbidden explosive as defined in 49 CFR 173.51, or a Class A explosive as defined in 40 CFR 173.53 or a Class B explosive as defined in 49 CFR 173.88.

Examples	Nature of Hazard
Forbidden Explosives	
Diethylene glycol di-nitrate	
Chlorate with ammonium or acid metal salts	
Unstabilized nitroglycerine and nitrocellulose	spontaneous detonation, extremely shock-, heat-, and friction-sensitive
Initiating explosives (See Class A explosives below) if dry	(transportation of these materials is forbidden under DOT regulations)
Di-nitrosalicylic acid	
Nitrogen tri-iodide	
Chlorine dioxide	
Perchloric acid 72%	
Class A Explosives	
TNT	high explosive, detonates readily if ignited
PETN	
Initiating explosives	
Lead or silver styphnate	
Silver tetrazene	extremely shock- and friction-sensitive if dry, must be transported wet in small quantities
Gold or mercury fulminate	
Diazo dinitrophenol	
Lead 2-4 dinitroresorcinate	
Class B Explosives	
Stabilized nitrocellulose	
Stabilized nitroglycerin	explosive combustion but unlikely to detonate
Rocket propellants	
Smokeless powder	

APPENDIX B

EXAMPLES OF ALTERNATIVE TREATMENT TECHNOLOGY

LIST OF EXHIBITS

Class I A	Treatment Matrix	
	Triethyl Aluminum	Combustion
	Triethyl Aluminum	Storage
I B	(No examples)	
I C	Treatment Matrix	
	Chromic Acid	Reduction
	Pechloric Acid	Reduction
	Sodium Chlorate	Reduction
Class II	Treatment Matrix	
	Acetic Anhydride	Storage
	Acetic Anhydride	Hydrolysis/Neutralization
	Acetic Anhydride	Combustion
	Chloracetone	Combustion
	Glyoxal	Combustion
Class III	Treatment Matrix	
	Sodium	Storage
	Sodium	Combustion
Class IV	Treatment Matrix	
	Phosphorus Trichloride	Storage
	Phosphorus Trichloride	Neutralization
	Titanium Tetrachloride	Storage
	Titanium Tetrachloride	Neutralization

Class V	Treatment Matrix	
	Sodium Cyanide	Alkaline Chlorination
	Sodium Cyanide	Peroxide Oxidation
	Sodium Cyanide	Electrolytic Oxidation
	Phosphorus Pentasulfide	Encapsulation/Landfill
	Phosphorus Pentasulfide	Peroxide Oxidation

Class VI	Treatment Matrix	
	Sodium Azide	Reaction with ceric ammonium acetate
	Parathion	Incineration
	Ammonium Nitrate	Reaction with soda ash

Class VII	Treatment Matrix	
	Benzoyl Peroxide	Combustion
	Benzoyl Peroxide	Reduction
	Ethylene Oxide	Combustion
	Picric Acid	Incineration

Class IA - Normally Unstable, Undergoes Violent Change without Detonation

Waste	Treatment Group	Technology	Treatment Feasibility	Applicability	Chemical & Equipment	Operator Requirements	Residual Production	Advantages/Disadvantages	Relative Cost
Triethylaluminum	Containment	Storage	+	0	-	+	N.A.	-	-
Triethylaluminum	Destruction	Combustion	+	0	+	0	+	0	+

Chemical:	Triethylaluminum
Waste Description:	waste solutions of 100% triethylaluminum
Destruction Technology:	Store in metal cylinder which protects the triethylaluminum from exposure to the atmosphere and water. Cylinders should be isolated in an explosion containment building.[1,2]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Containment cylinders utilized
Applicability	0	Applicable for temporary storage
Chemicals & Equipment	-	Explosion containment building recommended
Operator Requirements	+	Unskilled labor with adequate supervision
Residual Production	-	N/A
Advantages/ Disadvantages	-	Potential explosion hazard during storage
Cost	-	Capital expenditure for explosion containment building

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216582.

2. Fire Protection Guide on Hazardous Materials, 7th Edition, National Fire Protection Association, Boston, MA, 1978, p.

Chemical:	Triethylaluminum
Waste Description:	waste solutions of 100% triethylaluminum
Destruction Technology:	Mix with excess soda ash, place in iron pan, cover with combustible material (i.e., wood, paper) and burn in open area.[1]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Simple procedure
Applicability	0	Small batch operations
Chemicals & Equipment	+	Common materials
Operator Requirements	0	Safety procedures must be followed to prevent premature reaction or explosion
Residual Production	+	Non-hazardous
Advantages/ Disadvantages	0	Potential for accidental explosion
Cost	+	Low cost

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216582.

Class IB - Normally Unstable, Undergoes Violent Change without Detonation (Oxidizers)

Waste	Treatment Group	Technology	Treatment Feasibility	Applicability	Chemical & Equipment	Operator Requirements	Residual Production	Advantages/Disadvantages	Relative Cost	
Chromic Acid	Destruction	Reduction	+	+	+	+	0	+	0	
Perchloric Acid	Destruction	Reduction	+	+	+	+	+	+	0	
Sodium Chlorate	Destruction	Reduction	+	+	+	+	+	+	0	

Chemical:	Chromic Acid
Waste Description:	unused chromic acid - 100% pure
Destruction Technology:	Reduction with excess sodium metabisulfite, sodium bisulfite, or sodium sulfite (hexavalent chrome is reduced to the less hazardous trivalent form).[1]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Well established procedure
Applicability	+	Batch or continuous operation
Chemicals & Equipment	+	Simple equipment
Operator Requirements	+	Semi-skilled labor with adequate supervision
Residual Production	0	Aqueous solution of trivalent chromium
Advantages/ Disadvantages	+	Residual should be treated by precipitation with alkali to remove chromium
Cost	0	Chemicals are a major cost item

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216646.

Chemical:	Perchloric Acid
Waste Description:	unused perchloric acid - 60-70%
Destruction Technology:	Reduction with excess sodium bisulfite. Mix with bisulfite with perchloric acid solution, acidify with H_2SO_4 and after reduction is completed, neutralize[1].

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Well established procedure
Applicability	+	Batch or continuous operation
Chemicals & Equipment	+	Simple equipment
Operator Requirements	+	Semi-skilled labor with adequate supervision
Residual Production	+	Non-hazardous
Advantages/ Disadvantages	+	Simple process/cost
Cost	0	Chemicals are a major cost item

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216846.

Chemical:	Sodium Chlorate
Waste Description:	unused sodium chlorate
Destruction Technology:	Reduction with excess sodium bisulfite solution followed by neutralization.[1]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Well established procedure
Applicability	+	Batch or continuous operation
Chemicals & Equipment	+	Simple equipment
Operator Requirements	+	Semi-skilled labor with adequate supervision
Residual Production	+	Non-hazardous
Advantages/ Disadvantages	+	Simple process
Cost	0	Chemicals are a major cost item

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216890.

Class II - Reacts Violently with Water

Waste	Treatment Group	Technology	Treatment Feasibility	Applicability	Chemical & Equipment	Operator Requirements	Residual Production	Advantages/Disadvantages	Relative Cost
Acetic Anhydride	Containment	Temporary Storage	+	0	0	+	N.A.	0	-
Acetic Anhydride	Destruction	Hydrolysis/Neutralization	+	0	+	0	0	0	0
Acetic Anhydride	Destruction	Combustion	+	0	+	0	+	0	+
Chloroacetone	Destruction	Combustion	+	0	+	+	-	-	+
Glyoxal	Destruction	Combustion	+	0	+	+	-	-	+

Chemical: Acetic Anhydride

Waste Description: waste solutions of 100% acetic anhydride

Destruction Technology: Store in glass jugs, aluminum containers or stainless steel containers. Isolate from ignition sources, area should be cool and well ventilated.[1,2]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Established storage procedure
Applicability	0	Temporary storage
Chemicals & Equipment	0	Requires corrosion resistant containers
Operator Requirements	+	Unskilled labor with adequate supervision
Residual Production	-	N/A
Advantages/ Disadvantages	0	Inside storage requires approved flammable storage area
Cost	-	Low cost

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216567.

2. Fire Protection Guide on Hazardous Materials, 7th Edition, National Fire Protection Association, Boston, MA, 1978, p. 49-28.

Chemical:	Acetic Anhydride
Waste Description:	waste solutions of 100% acetic anhydride
Destruction Technology:	Hydrolysis/neutralization. Slowly add acetic anhydride to water, neutralize the acetic acid. Acid formed with sodium bicarbonate or lime.

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Well established procedure
Applicability	0	Batch or continuous operation
Chemicals & Equipment	+	Readily available chemicals and equipment
Operator Requirements	0	Semi-skilled labor with adequate supervision
Residual Production	0	Acetic acid should be discharged to sewer
Advantages/ Disadvantages	0	Simple procedure/hydrolysis may generate large amounts of heat and emit fumes
Cost	0	Low cost, neutralization chemicals required

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216567.

Chemical: Acetic Anhydride

Waste Description: waste solutions of 100% acetic anhydride

Destruction Technology: Combustion, mix with sand and burn in open area.[1]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Simple procedure
Applicability	0	Limited to small quantity batch operations
Chemicals & Equipment	+	Requires only sand
Operator Requirements	0	Unskilled operator with adequate supervision. Safety cautions must be practiced to prevent inhalation of toxic fumes
Residual Production	+	Non-hazardous
Advantages/ Disadvantages	0	Simple, low cost materials/emission of toxic vapors
Cost	+	Low cost

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216567.

Chemical:	Chloroacetone
Waste Description:	contaminated or unused chloroacetone
Destruction Technology:	Mix with vermiculite, soda ash, or sand, and combustible trash, burn in incinerator or open pit.[1]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Simple process
Applicability	0	Limited to small quantity, batch operations
Chemicals & Equipment	+	Readily available materials
Operator Requirements	+	Unskilled labor with adequate supervision
Residual Production	-	Possible emission of toxic gases
Advantages/ Disadvantages	-	May be prohibited by local codes except in emergency
Cost	+	Low cost

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216802.

Chemical:	Glyoxal
Waste Description:	spent glyoxal solutions
Destruction Technology:	Combustion, mix with vermiculite, soda ash or sand, burn in open area.[1]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Simple procedure
Applicability	0	Limited to small quantity, batch operation
Chemicals & Equipment	+	Readily available materials
Operator Requirements	+	Unskilled labor with adequate supervision
Residual Production	-	Non-hazardous
Advantages/ Disadvantages	-	May be prohibited by local codes except in emergency
Cost	+	Low cost

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216739.

Class III - Forms Potentially Explosive Mixtures With Water

Waste	Treatment Group	Technology	Treatment Feasibility	Applicability	Chemical & Equipment	Operator Requirements	Residual Production	Advantages/Disadvantages	Relative Cost
Sodium	Containment	Temporary Storage	+	+	+	0	N.A.	0	0
Sodium	Destruction	Combustion	+	0	+	+	0	+	+

Chemical: Sodium

Waste Description: unused sodium pieces

Destruction Technology: Store in sealed drums under kerosene (or similar liquids) which contain no oxygen. Keep away from water.[1,2]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Well established technology
Applicability	+	Common practice
Chemicals & Equipment	+	Containers and liquids are readily available
Operator Requirements	0	Unskilled labor with adequate supervision
Residual Production	-	N/A
Advantages/ Disadvantages	0	Can accumulate batches for treatment. Need isolated fire resistant storage
Cost	+	Low cost

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216885.

2. Fire Protection Guide on Hazardous Materials, 7th Edition, National Fire Protection Association, Boston, MA, 1978, p. 49-260.

Chemical: Sodium

Waste Description: unused sodium

Destruction Technology: Combustion, add to fire of oil soaked rags or charcoal in a dry, welded steel pan.[1]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Simple procedure
Applicability	0	Limited to small quantity batch operations
Chemicals & Equipment	+	Low technology equipment
Operator Requirements	+	Unskilled labor with adequate supervision
Residual Production	0	Residue is corrosive
Advantages/ Disadvantages	+	May be prohibited by local codes except in emergency
Cost	+	Low cost

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216885.

Class IV - Generate Toxic Gases Which Present a Danger to Health or the Environment

Waste	Treatment Group	Technology	Treatment Feasibility	Applicability	Chemical & Equipment	Operator Requirements	Residual Production	Advantages/Disadvantages	Relative Cost
Phosphorus Trichloride	Containment	Storage	+	+	+	+	N.A.	0	0
Phosphorus Trichloride	Destruction	React with soda ash, Neutralize	+	0	+	0	+	0	0
Titanium Tetrachloride	Containment	Storage	+	+	+	+	N.A.	0	0
Titanium Tetrachloride	Destruction	React with $Na(HCO_3)^2$ Neutralize	+	0	+	0	0	+	0

Chemical: Phosphorus Trichloride

Waste Description: unused solutions of 100% PCl_3

Destruction Technology: Store in tightly closed containers in a cool, dry area, protect from exposure to water.[1,2]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Accepted storage procedure
Applicability	+	Temporary storage
Chemicals & Equipment	+	Approved isolated storage area
Operator Requirements	+	Unskilled labor with adequate supervision
Residual Production	-	N/A
Advantages/ Disadvantages	0	Suitable for temporary storage
Cost	0	Low cost

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216858.

2. Fire Protection Guide on Hazardous Materials, 7th Edition, National Fire Protection Association, Boston, MA, 1978, p. 49-237.

Chemical: Phosphorus Trichloride

Waste Description: unused solutions of 100% PCl_3

Destruction Technology: Pour onto soda ash or lime, mix with water.[1]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Simple procedure
Applicability	0	Limited to small quantity, batch operations
Chemicals & Equipment	+	Readily available chemicals and simple equipment
Operator Requirements	0	Unskilled labor with adequate supervision
Residual Production	+	Non-hazardous
Advantages/ Disadvantages	0	Possible evolution of hydrochloric acid vapor
Cost	0	Low cost

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216858.

Chemical: Titanium Chloride

Waste Description: unused titanium chloride

Destruction Technology: Store in tightly sealed, heavy gauge steel drums.[1,2] Protect from exposure to water.

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Accepted storage procedure
Applicability	+	Temporary storage
Chemicals & Equipment	+	Approved isolated storage area
Operator Requirements	+	Unskilled labor with adequate supervision
Residual Production	-	N/A
Advantages/ Disadvantages	0	Suitable for temporary storage
Cost	0	Low cost

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216858.

2. Fire Protection Guide on Hazardous Materials, 7th Edition, National Fire Protection Association, Boston, MA, 1978, p. 49-283.

Chemical:	Titanium Chloride
Waste Description:	unused titanium chloride
Destruction Technology:	Pour on layer of sodium bicarbonate, mix continue to stir while spraying with ammonium hydroxide, when smoke subsides cover with ice, and neutralize.[1]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Simple procedure
Applicability	0	Limited to small batch operations
Chemicals & Equipment	+	Readily available chemicals and equipment
Operator Requirements	0	Unskilled labor with adequate supervision
Residual Production	0	Ammonium chloride vapor
Advantages/ Disadvantages	+	Air pollution from vapor
Cost	0	Chemical cost is significant

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216858.

Class V - Cyanide/Sulfide

Waste	Treatment Group	Technology	Treatment Feasibility	Applicability	Chemical & Equipment	Operator Requirements	Residual Production	Advantages/Disadvantages	Relative Cost
Sodium Cyanide	Destruction	Alkaline chlorination	+	+	+	0	+	+	0
Sodium Cyanide	Destruction	Hydrogen peroxide oxidation	+	0	+	0	+	0	0
Phosphorus Pentasulfide	Containment	Encapsulation/Landfill	+	+	+	+	-	0	+
Phosphorus Pentasulfide	Destruction	Hydrogen peroxide oxidation	+	0	0	+	0	0	-

Chemical:	Cyanide
Waste Description:	concentrated sodium cyanide cleaning solution
Destruction Technology:	Alakline Chlorination - oxidation of aqueous cyanide in a two-stage reaction where cyanide is oxidized to cyanate at pH 9-11 in stage one and cyanate is oxidized to nitrogen and bicarbonate in stage two at a pH of 8.5. Reaction time of 25-30 minutes in each stage.[1]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Widely used water treatment process
Applicability	+	Applicable to large scale batch or continuous oxidation of cyanide
Chemicals & Equipment	+	Chlorine gas and hypochlorite available industrially. Reaction tanks, pumps, monitors are standard equipment
Operator Requirements	0	Skilled labor for monitoring instruments and observance of safety procedures is necessary
Residual Production	+	No primary sludge; secondary sludge (i.e., metal hydroxides) may settle in reaction tanks
Advantages/ Disadvantages	+	Requires engineering controls to ensure safe operation
Cost	0	High capital investment

1. Environmental Pollution Control Alternatives: Economic of Wastewater Treatment Alternatives for the Electroplating Industry. EPA 625/5-79-016, Technology Transfer, EPA, IERL, Cincinnati, OH, June 1979.

Chemical:	Cyanide
Waste Description:	concentrated sodium cyanide cleaning solutions
Destruction Technology:	Hydrogen peroxide oxidation oxidizes cyanide to cyanate. The reactio is run in a batch mode at a pH of 9-10 and a temperature of 120° - 130°F. Reaction time is approximately 1 hour.

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Has been applied commercially
Applicability	0	Applicable on small batch scale
Chemicals & Equipment	+	Hydrogen peroxide available industrially, widely avaialble as are reaction tanks, pumps, and monitoring equipment
Operator Requirements	0	Skilled labor for monitoring instruments and observance of safety procedures are necessary
Residual Production	+	Cyanate which is still toxic
Advantages/ Disadvantages	0	Only oxidizes cyanide to the less toxic cyanate
Cost	0	Lower cost than alkaline chlorination

1. Environmental Pollution Control Alternatives: Economic of Wastewater Treatment Alternatives for the Electroplating Industry. EPA 625/5-79-016, Technology Transfer, EPA, IERL, Cincinnati, OH, June 1979.

Chemical:	Sulfides
Waste Description:	phosphorus pentasulfide production waste stream (6-7% phosphorus pentasulfide)
Destruction Technology:	Encapsulation by cementation or lime-based pozzolanic materials. In cementation, a waste slurry is mixed with cement and allowed to set. In lime-based pozzolanic encapsulation a waste slurry is mixed with lime and a pozzolanic material (i.e., fly ash) and water are allowed to set.[1]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	
Applicability	+	
Chemicals & Equipment		Cement, lime pozzolanic material readily available, common processing equipment which is readily available
Operator Requirements	+	Semi-skilled labor with adequate supervision
Residual Production	-	Non-hazardous but double the weight and volume of original waste
Advantages/ Disadvantages	0	Permanent containment of residual is required
Cost	+	High materials costs

1. Suvery of Solidification/Stabilization Technology for Hazardous Industrial Wastes by U.S. Army WES, Vicksburg, Mississippi, for U.S. EPA MERL, Cincinnati, OH, 45268, under Interagency Agreement No. EPA-04-0569.

Chemical:	Sulfides
Waste Description:	phosphorus pentasulfide production waste stream (6-7% phosphorus pentasulfide)
Destruction Technology:	Mix waste with large excess of water, oxidize hydrogen sulfide produced with hydrogen peroxide to sulfur.[1]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Hydrogen peroxide oxidation is widely used
Applicability	0	Batch operation suitable for small amounts
Chemicals & Equipment	0	Hydrogen peroxide available industrially requires reaction tanks, pumps, etc.
Operator Requirements	+	Semi-skilled labor with adequate supervision
Residual Production	0	Non-hazardous (sulfur)
Advantages/ Disadvantages	0	Potential for evolution of highly toxic hydrogen sulfide
Cost	-	High cost for hydrogen peroxide

1. Suvery of Solidification/Stabilization Technology for Hazardous Industrial Wastes by U.S. Army WES, Vicksburg, Mississippi, for U.S. EPA MERL, Cincinnati, OH, 45268, under Interagency Agreement No. EPA-04-0569.

Class VI - Capable of detonation or explosion if strongly heated or initiated

Waste	Treatment Group	Technology	Treatment Feasibility	Applicability	Chemical & Equipment	Operator Requirements	Residual Production	Advantages/Disadvantages	Relative Cost	
Sodium Azide	Destruction	React with ceric ammonium acetate	+	0	+	+	+	+		
Parathion	Destruction	Incineration	+	+	-	0	0	0	-	
Ammonium Nitrate	Destruction	React with soda ash	+	+	+	+	-	0	0	

Chemical:	Sodium Azide
Waste Description:	unused sodium azide, 100% pure
Destruction Technology:	React with excess ceric ammonium acetate, mix and cool the reaction.[1]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Laboratory procedure
Applicability	0	Small batch operations
Chemicals & Equipment	+	Readily available chemicals and equipment
Operator Requirements	+	Semi-skilled labor with adequate supervision
Residual Production	+	Non-hazardous
Advantages/ Disadvantages	+	Simple procedure
Cost	0	Moderate chemicals cost

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216887.

Chemical: Parathion

Waste Description: unused parathion insecticide

Destruction Technology: Mix with sand and limestone and incinerate.[1]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Uses existing incinerator
Applicability	+	Small or large batches
Chemicals & Equipment	-	Incinerator is required
Operator Requirements	0	Skilled labor required
Residual Production	0	Scrubber sludge
Advantages/ Disadvantages	0	Need access to hazardous waste incinerator with alkaline scrubber
Cost	-	High capital investment for incinerator

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216542.

Chemical: Ammonium Nitrate

Waste Description: unused ammonium nitrate, 100%

Destruction Technology: Dilute with water, react with excess soda ash, neutralize with dilute acid.[1]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Simple technology
Applicability	+	Limited to small batch operation
Chemicals & Equipment	+	Common chemicals and processing equipment
Operator Requirements	+	Unskilled labor with adequate supervision
Residual Production	-	Non-hazardous effluent to sewer
Advantages/ Disadvantages	0	Simple technique
Cost	0	Low cost

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216588.

Class VII - Readily Capable of Decomposition or Detonation at STP

Waste	Treatment Group	Technology	Treatment Feasibility	Applicability	Chemical & Equipment	Operator Requirements	Residual Production	Advantages/Disadvantages	Relative Cost	
Benzoyl Peroxide	Destruction	Combustion	+	0	+	+	-	-	+	
Ethylene Oxide	Destruction	Combustion	+	0	+	-	+	0	-	
Picric Acid	Destruction	Incineration	+	0	0	0	-	-	-	

Chemical: Benzoyl Peroxide

Waste Description: small lots - 1 lb. container-waste reagent

Destruction Technology: Mix with equal weight of wet vermiculute or lime and burn in open area.[1]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Simple process
Applicability	0	Limited to small batch operation
Chemicals & Equipment	+	
Operator Requirements	+	Unskilled operator with adequate supervision
Residual Production	-	Potential for explosion
Advantages/ Disadvantages	-	Low cost/potential air pollution problems
Cost	+	Low cost

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216603.

2. Fire Protection Guide on Hazardous Materials, 7th Edition, National Fire Protection Association, Boston, MA, 1978, p. 49-113.

Chemical: Ethylene Oxide

Waste Description: spent ethylene oxide

Destruction Technology: Incineration, dissolve in alcohol and incinerate.[1,2]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Well established process
Applicability	0	Applicable to small batch operation
Chemicals & Equipment	+	Common chemicals and equipment
Operator Requirements	-	Semi-skilled labor with adequate supervision
Residual Production	+	None
Advantages/ Disadvantages	0	Peroxides may be present in aged ethylene oxide creating an explosion hazard
Cost	+	High capital investment

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7216724.

2. Fire Protection Guide on Hazardous Materials, 7th Edition, National Fire Protection Association, Boston, MA, 1978, p. 49-156.

Chemical:	Picric Acid
Waste Description:	unused picric acid, 100%
Destruction Technology:	Combustion, add 10% water, mix with 90/10 mixture of sand and soda ash, load in paper cartons, burn in incinerator.[1,2]

Evaluation Table

Criteria	Rating	Comments
Technical Feasibility	+	Established procedure
Applicability	0	Limited to small batch operations
Chemicals & Equipment	0	Requires an incinerator with an alkaline scrubber
Operator Requirements	0	Semi-skilled labor with adequate supervision
Residual Production	-	Acid vapors which may require a scrubber which will in turn produce a sludge
Advantages/ Disadvantages	-	Must be kept out of contact with metals. Possible explosion hazard
Cost	-	High capital investment

1. NIH/EPA Chemical Information System (CIS), OIL and Hazardous Materials Technical Assistance Data System (OHM-TADS), Chemical Information Systems, Inc., 7215 York Road, Baltimore, MD, 21212. Accession No. 7217407.

2. Fire Protection Guide on Hazardous Materials, 7th Edition, National Fire Protection Association, Boston, MA, 1978, p. 49-242.